Ultra-Precision Machine Spindle Using Porous Ceramic Bearings

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Air bearing spindles have typically been used for ultra-precision machine applications, due to the low asynchronous error motion and the high rotational accuracies achievable. Traditional oil-fluid-film bearings have not been able to match the accuracies of air bearings, but they have the advantage higher stiffness and improved dampening capabilities. With the advent of new oil-fluid-film porous ceramic bearing materials, we may now be able to have the best of both worlds: the accuracy of an air bearing with the high stiffness and improved dampening capabilities of a traditional oil-fluid-film bearing.

Project Goals

The main project goal is to have a working spindle, applying porous ceramic bearing technology, which can be used on a future machine tool. The spindle will be thoroughly tested to ensure that it meets the performance requirements shown in the table.

Another goal of the project is to transfer the porous ceramic bearing technology from the academic field to LLNL, *i. e.*, to create spindle modeling software tools and to increase LLNL's level of understanding of issues in building porous ceramic bearing spindles.

Relevance to LLNL Mission

Single-point diamond turning of optics was pioneered at LLNL, which received an R&D 100 award for this work in 1978. Since that time, the sizes of the optics have become larger and the specifications

Work Head Performance Requirements

Speed	100 to 1,500 rpm, bi-directional
Load Capacity at Spindle Nose	500 lb. (227 kg) including work holding device
Error Motion: Axial	2 µin (50 nm)
Radial	2 µin (50 nm)
Static Stiffness: Axial	720 N/µm
Radial at Spindle Nose	300 N/µm

have grown more stringent. For example, in 1978 we were fabricating 5-cm optics, today we are fabricating optics that are 42 cm^2, and have a surface finish requirement of under 1.5 nm RMS and a transmitted wavefront of less than $\lambda/2$.

The work of this project will enable LLNL to continue its leadership in this field (see Fig. 1).

FY2004 Accomplishments and Results

This is a multiyear project that will be completed next year. Previous work included such tasks as: spindle and bearing models; fabrication of miscellaneous spindle and test hardware components; and fabrication, to a rough state, of the bearings and spindle rotor. This year we completed the fabrication of ceramic components; bearing gap analysis, based on actual ceramic bearing porosity; final precision machining of spindle bearings and rotor; and spindle thermal response modeling.

The optimum bearing porosity, determined by computational modeling of the ceramic bearings, was found to be 2×10^{-14} m^2. The measured porosity of the actual ceramic was 1.92×10^{-14} and 1.72×10^{-14} m^2 for the front and rear journal bearings, respectively (Fig. 2). The actual porosity values were then used in our spindle model to determine the other bearing parameters required to complete the final precision machining of spindle bearings and rotor. This work was completed and we received the spindle components ready for assembly and testing.

FY2005 Proposed Work

In FY2005, we will assemble and test the porous ceramic bearing spindle to confirm that it meets the original requirements shown in the table. A final report will be written and the results will be presented at the American Society for Precision Engineering annual conference.

Figure 2. Front journal and rear journal and thrust bearing assemblies. The light color components are made of porous ceramic.

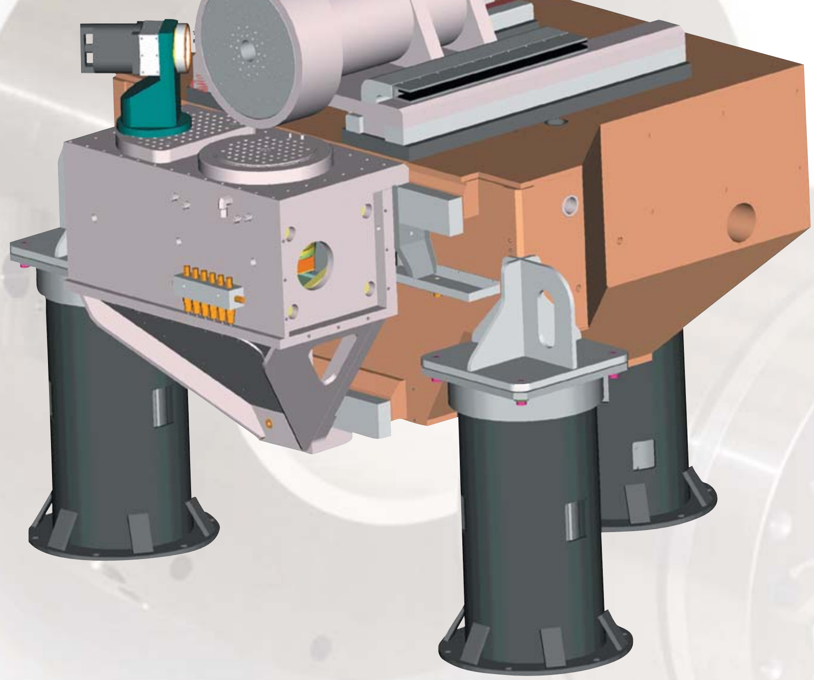

Figure 1. Conceptual drawing of the new Precision Optical Grinder and Lathe (POGAL) machine, the next-generation machine tool at LLNL.